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RS-485 Interface for Boiler Header Inspection Robot Prototype

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Abstract

This paper discusses the design of an RS-485 interface for Boiler Header Inspection Robot (BHIR) prototype. BHIR is a robot developed for inspection of boiler headers in thermal power plants which are enclosed pipes and can range from 3 to 20 meters in length. They are horizontal in configuration and have boiler tubes inlets and outlets. The current prototype is tether based and requires cables up to 20 meters. RS-485 interface is presented in this paper which is used to develop a communication link between PC-based control (GUI interface) with the BHIR Prototype on-board controller. Since RS-485 is reliable and stable in monitoring and controlling system, BHIR Prototype can work effectively throughout the length of the boiler header.

Keywords: RS-485; mobile robot;boiler header inspection

1. Introduction

Boiler headers are pressurized horizontal pipes with multiple inlets and outlets and can range up to 20 meters in length (based on database from Tenaga Nasional Berhad). The function of a boiler header is to prevent any boiler carryover by containing water solid from the steam mains in a thermal power plant (*Retrieved on 23 April 2011 from http://www.armstronginternational.com/ Armstrong steam-university-boiler-headers*). Well-functioning boiler header is essential to sustain the operation in protected condition. So, inspection activity is important for the boiler header system to detect signs of any possible defect such as crack, pitting and corrosion, protecting it from failure [1]. Boiler header is similar to the other piping systems for urban gases, nuclear power plant, chemical plant, etc. in geometry [2].

Data transmission during inspection activities over long-distance requires reliable equipment to prevent any miscommunication or missing data [3]. The efficiency of data transmission over long-distance is also required in inspection activities. Currently, BHIR prototype uses RS-485 interface with tethered cable, which is used to control the robot. It is also used as a data communication device between the controller and the robot during inspection inside boiler headers in power plants. This paper discusses the RS-485 base communication system for BHIR Prototype, and also introduces RS-485 interface as the best choice for data transmission of BHIR prototype over long-distance.

2. System Description

The BHIR prototype system is a PC-based control system. The structure of the control system is divided into two sub-sections; wheel controller and servo-motor controller which is shown in Fig. 1.

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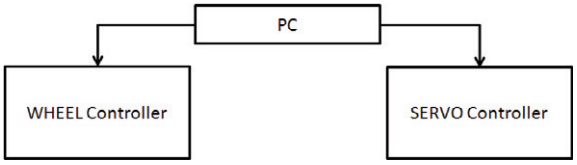

Fig. 1. Sub-section of BHIR prototype controller

The BHIR prototype control system adopts serial communication mode by using RS-485 interfacing unit [4], which has an advantage for long-distance communication and anti-jamming [5]. Communication process of BHIR prototype system is as shown in Fig. 2.

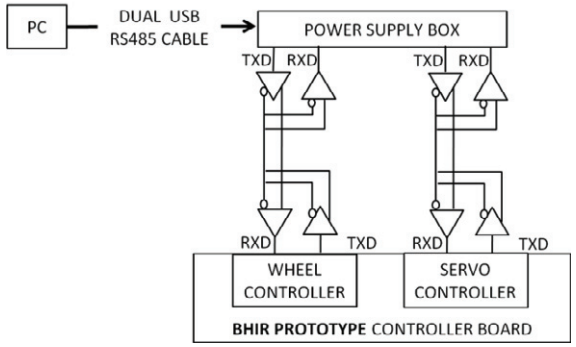

Fig. 2. RS-485 for BHIR prototype

3. Hardware Design

The hardware of BHIR Prototype control system is composed of wheel controller and servo motor controller, which is shown in Fig. 3.

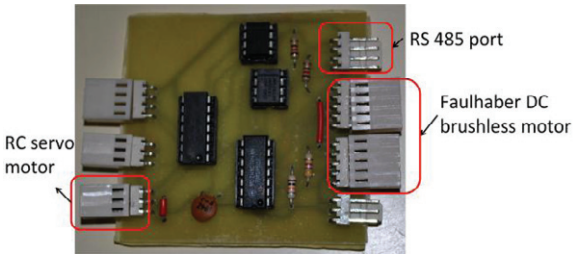

Fig. 3. Controller PCB for BHIR prototype

3.1. Wheel Controller

The wheel controller shown in Fig. 4 consists of Faulhaber DC brushless motor drivers, 74HCT04 and MAX-485 IC. For the wheel controller, two sets of Faulhaber DC brushless motor, which is equipped with motion controller is used. Considering that serial RS-232 communication is already embedded in the motion controller, the level shifter function is not needed. The RS-485 communication is selected to perform TTL level shifting operation.

The 74HCT04 is used to eliminate level shifting of RS-232 Faulhaber DC brushless motor. After the operation of level shifting from RS-232 to TTL level, TTL signal is again shifted to RS-485 differential signal via the MAX-485 IC of BHIR prototype controller board.

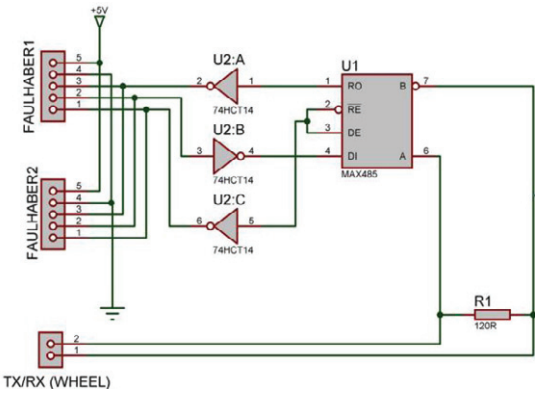

Fig. 4. Wheel controller for BHIR prototype

3.2. Servo Controller

Fig. 5 shows the servo controller which consists of PIC16F688, RC-servo motor and MAX-485 IC (servo controller for BHIR prototype).

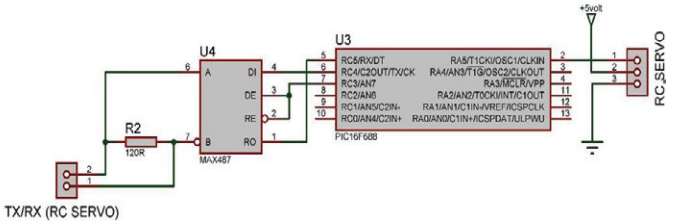

Fig. 5. Servo controller for BHIR prototype

4. GUI Design

Fig. 6 illustrates the Graphical User Interface (GUI) of the BHIR prototype, which is used to control the Faulhaber DC brushless motors and RC-servo motor. The GUI runs on Windows 7 platform and is developed using Visual C#. It controls the movement of the robot such as forward, reverse, left and right as well as the speed. The GUI also provides function for RC-servo motor positioning to adjust the fiber optic cable height. The feedback from the encoders and also RC-servo are also displayed on the GUI.

5. Communication System

RS-485 communication interface unit is utilized to resolve the level conversion between external devices (FAULHABER DC Brushless motor and RC-Servo motor) and the PC-based control, (RS-485 data cable and MAX-485 IC/driver). The detail is as follows:

5.1. RS-485 Data Cable

RS-485data cable is used as communication carrier for the BHIR prototype system. The main reason RS-485 is used for the system is because it uses differential signal which can transfer data over long-distance. The RS-485 data cable is made of two wire twisted in pair with characteristic impedance of 120Ω, bus matching is necessary to remove interference caused by reflections of transmission lines and to ensure glitch-free signal [6] as shown in Fig. 7.

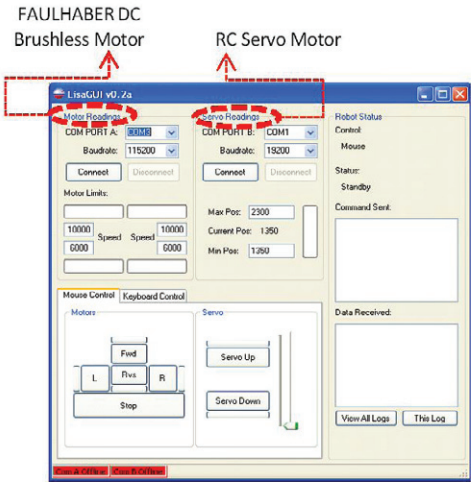

Fig. 6. BHIR prototype GUI

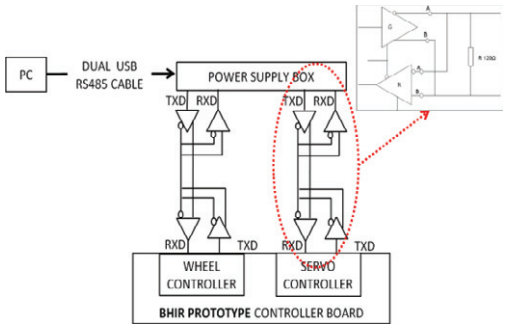

Fig. 7. Bus Matching

Fig. 7 also shows four RS-485 twisted data cable of BHIR Prototype, which is developed to interface with the wheel controller, and also for the RC-servo controller to communicate with the GUI.

The following factors have been considered in this BHIR prototype RS-485 data cabling (on board circuit):

i. Cable length:

- Increase in cable length would slowly destroy the signal intensity under particular frequency.
- Currently, BHIR Prototype cable length is about 20 meters, which is still acceptable.
- RS-485 twisted cable is constructed in 20 meters length, used to provide high data speed for long distance communication.

ii. Cable architecture:

- 24 AWG twisted cable is commonly used in RS-485 serial transmission system.
- The twisted wiring is necessary for RS-485 transmission system to overcome noise immunity.
- Differential signal which is provided in twisted cable is used to transmit data at high rates up to 20 meters length and through confined space.

5.2. RS-485 Driver

The MAX-485 IC is used as a driver data transmission for BHIR prototype. The MAX-485 characteristics are [6]:

- Low power transceiver for RS-485 serial communication
- Driver slew rate can transmit up to 2.5Mbps (transmission speed) [7]
- Designed for half duplex application

The description above is suitable to be applied in accessing BHIR prototype from the GUI through long-distance data communication.

5.3. RS-485 Mapping

Fig. 8 shows the overall BHIR Prototype schematic diagram that utilizes serial communication port (UART). The BHIR Prototype controllers adopt two MAX-485 chips to construct a standard RS-485 interface [8].

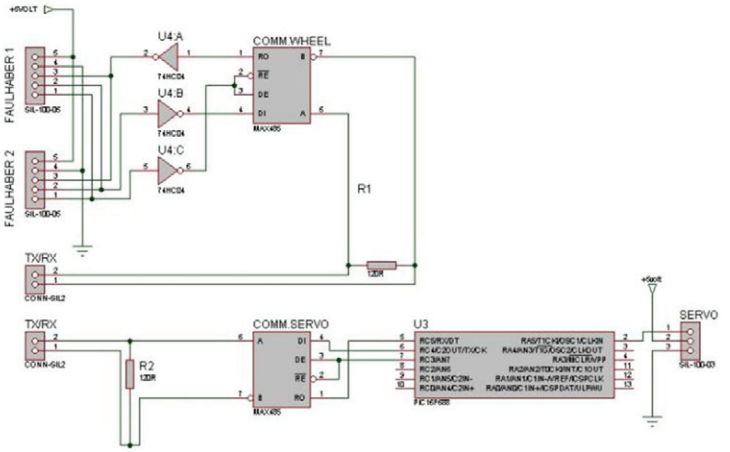

Fig. 8. BHIR prototype schematic diagram

The USB to dual RS-485 converter module is used to replace the standard 9-pin serial ports [9] to send and receive data via RS-485.

The BHIR prototype controller is equipped with two individual virtual COM ports for the human interface (PC-based control) which are initialized as COM port A and COM port B.

COM port A is mapped as RS485A and COM port B is mapped as RS485B. The RS485A communicates with the wheel controller (Faulhaber DC brushless motors) while RS485B communicates with the RC-servo controller (for the fiber optic holder on the robot) as shown in Table 1.

Table 1. Description of RS-485 system for BHIR prototype

Activate	RS-485	COMM Port
DC Brushless Motor	RS-485 A	COM Port A
RC Servo Motor	RS-485 B	COM Port B

5.4. RS-485 Data Communication

As mentioned earlier, BHIR prototype consists of two controller parts (RC-Servo controller and Wheel controller) and they are controlled through the GUI. The BHIR prototype communication process can be represented as a flowchart shown in Fig. 9.

All the communication process is launched through the GUI interface, which send commands through COM port A and COM Port B.

COM Port A has a baud rate of 115.2kb/s. To program the Faulhaber DC brushless motor, higher-level language is used. The frame format to program Faulhaber DC brushless motor consists of node no, command, argument and carriage return. The structure of Faulhaber DC brushless motor frame format in ASCII commands is as shown in Fig. 10.

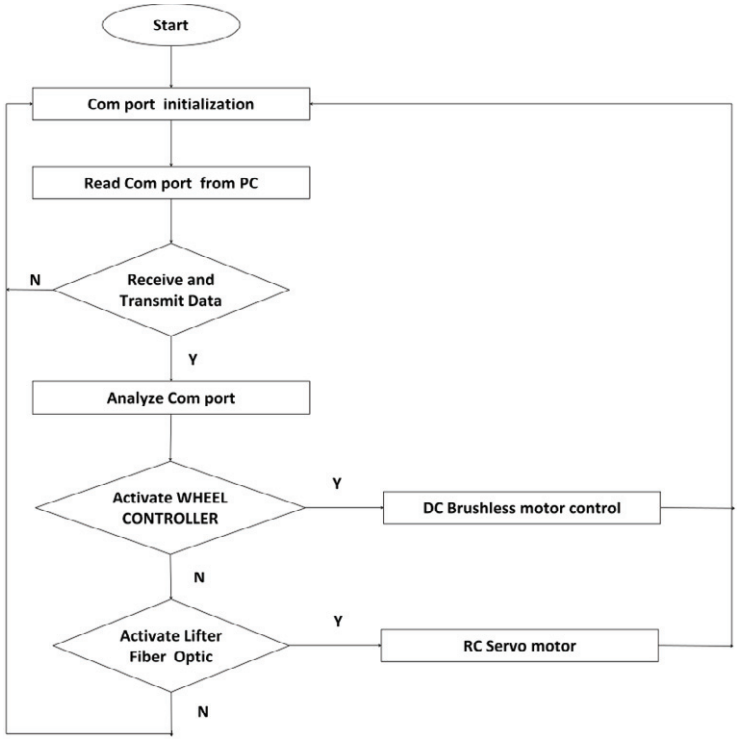

Fig. 9. BHIR prototype communication process flow chart

Node no	Command	Argument	CR

Fig. 10. Faulhaber DC Brushless motor frame format

COM Port B has a baud rate of 19.6kb/s and the program is written in C language. RC-servo motor controller used three components for its communication protocol of the frame format. The components are command header, data and carriage return. The command header uses char characteristic to initialize the RC servo motor controller in function call for the RC-servo controller.

Based on the two formats above, the GUI is developed using Microsoft C# to control both the Faulhaber DC brushless motor and RC-servo motor.

5.5. RS-485 vs RS-232

Communication for the BHIR prototype can also be done using RS-232. As mentioned is Section III-A, serial RS232 communication is already embedded in motion controller of the Faulhaber motors. However, there is data speed limitation for the RS-232. At 20 meters, RS232 can only operate at 19.2kb/s while RS-485 can operate up to 4Mb/s. This allows communication to be set to the highest speed capable by the motion controller which is 115.2kb/s. Furthermore, by operating at 115.2kb/s, the communication distance can be increased to more than 600 meters.

Increase in communication speed allows higher command rates. The following commands for the Faulhaber DC brushless motor shown in Table 2 are used for comparison of command rate between RS-232 and RS-485. Each character in the command in transmitted using 1 start bit , 8 data bits and 1 stop bit which contribute to a total of 10 bits per character. Fig. 11 shows the command rate comparison for RS-232 operating at 19.2kb/s with RS-485 operating at 115.2kb/s for a 20 meter cable length. In summary, using RS-485 for the BHIR prototype increases the command rate by 600% compared to RS-232.

Table 2. Faulhaber command list

Command	Meaning	No of bits
"0v0/r"	Node 0, motor stop	40
"1v100/r"	Node 1, motor cw at speed 100 units	60
"0v1000/r"	Node 0, motor cw at speed 1000 units	70
"1v-2000/r"	Node 1, motor ccw at speed 2000 units	80

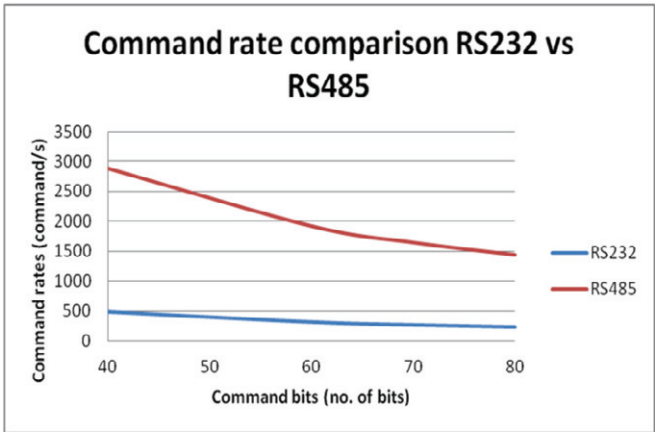

Fig. 11. Command rate comparison between RS-232 vs RS-485

Conclusion

The BHIR prototype is capable to achieve a reliable and stable data transmission throughout the 20 meter cable length. This is due to the BHIR prototype's RS-485 based communication systems providing good responds. When the user sends a command either to the wheel controller or to the servo controller, the BHIR prototype is capable to respond in real-time while receiving the command through the RS-485 interface system. Compared with RS-232, the RS-485 increases the command rate up to 600%.

The development of RS-485 interface for BHIR Prototype discussed in this paper can still be further improved by reducing the overall circuit size since size is a major concern for the robot.

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